

## Bottom Interaction in Ocean Acoustic Propagation

Ralph A. Stephen  
Woods Hole Oceanographic Institution  
360 Woods Hole Road (MS#24)  
Woods Hole, MA 02543  
phone: (508) 289-2583 fax: (508) 457-2150 email: [rstephen@whoi.edu](mailto:rstephen@whoi.edu)

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### LONG-TERM GOALS

The long term objective here is to understand the dominant physical mechanisms responsible for propagation and scattering over distances from tens to thousands of kilometers in the deep ocean where the sound channel is not bottom limited. The specific goal is to study the role of bottom interaction and bathymetry on the stability, statistics, spatial distribution and predictability of broadband acoustic signals observed just above and on the deep seafloor (greater than the critical depth). What is the relationship between the seismic (ground motion) noise on the seafloor and the acoustic noise in the water column? What governs the trade-offs in contributions from local and distant storms and in contributions from local and distant shipping? How effective is seafloor bathymetry at stripping distant shipping noise from the ambient noise field?

This project addresses "the effects of environmental variability induced by ocean internal waves, internal tides and mesoscale processes, and by bathymetric features including seamounts and ridges, on the stability, statistics, spatial distribution and predictability of broadband acoustic signals..." (quote from the Ocean Acoustics web page). Understanding long range acoustic propagation in the ocean is essential for a broad range of Navy applications such as the acoustic detection of ships and submarines at long ranges, avoiding detection of ships and submarines, long range command and communications to submerged assets, and improving understanding of the environment through which the Navy operates. The long-term objective here is to understand the dominant physical mechanisms responsible for propagation and scattering in the deep ocean where the sound channel is not bottom limited.

### OBJECTIVES

This project quantitatively compares the signal and noise levels in the Philippine Sea in the 50-400Hz band on the hydrophones and geophones at the seafloor to the hydrophones suspended up to 1 kilometer above the seafloor, for ranges from near zero to 250km. We also study seafloor ambient noise in the Philippine Sea in the band from 0.03 - 80Hz and compare it to other deep-water sites in the Pacific Ocean. Specific questions to be addressed include: i) Is there evidence for Deep Seafloor Arrivals in the Philippine Sea (water depths around 5500m) that are similar to the ones observed on NPAL04 (water depths around 5000m)? ii) What is the frequency dependence of the deep arrival structure from 50 - 400Hz? iii) What is the range dependence of the deep arrival structure out to 250km? iv) What is the azimuth dependence of the deep arrival structure? v) What are the relative

## Report Documentation Page

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SNRs of arrivals on vertical and horizontal geophones, co-located seafloor hydrophones and moored hydrophones (from 20m to 1000m off the bottom - 15 hydrophones at about 60m separation)? vi) What are the phase relationships between pressure and vertical and horizontal particle motion for deep seafloor arrivals and ambient noise? vii) What is the relationship between the observed deep arrival structure and the PE predicted arrival structure? viii) How far above the seafloor does the Deep Seafloor Arrival structure extend?

## APPROACH

The major effort in this first year was data reduction. Three types of figures form the basis for the data reduction and analysis:

- 1) Time series of the time compressed traces as a function of range (for the eight 50km radials and the one 250km long line), as a function of azimuth (for the Star of David pattern) and as a function of time (for the station stops). For the 50km radials and Star of David we transmitted M-sequences at 77.5, 155 and 310Hz; for the 250km long-range tow we transmitted one M-sequence at 77.5Hz; and for the eighteen station stops we transmitted M-sequences at 77.5, 102.3, 155, 204.6 and 310Hz.
- 2) SNR summaries, similar to Figure 26 of the cruise report (Stephen *et al.*, 2011), are an excellent way to reduce an intensive data set (we transmitted for 11.5days) into a few meaningful parameters.
- 3) Spectrograms for all receivers. The fifteen HMs on the O-DVLA recorded for 24days (360 sensor-days at 1953.125sps). The sensors on the OBSs (four each for the three short-period OBSs, at 1000sps, one HM for each of the short-period OBSs, at 1953.125sps, and four each for the two long-period OBSs, at 200sps) recorded for about 12days (276 sensor-days). Continuous data for a total of 636 sensor-days was acquired. All instruments were recording during the typhoon on JD130 so we have samples of calm and rough conditions.

## WORK COMPLETED

Time compressions, SNR summaries and spectrograms have been generated for the whole data set.

## RESULTS

Is there any indication of Deep Seafloor Arrivals in the Philippine Sea, similar to those observed on NPAL04? Yes. Figures 1 to 3 show stacked, time-compressed traces for the Northeast line on the lowest element of the DVLA and on the Hydrophone Module (HM) and vertical geophone on the West OBS. The HM on the West OBS is about a meter above the seafloor and is essentially co-located with the geophone. Neither HM sees significant arrivals other than the well-known direct and bottom-reflected surface-reflected (BDSR) paths. The vertical geophone, on the other hand, shows two clear events occurring after the BDSR arrivals. If these were water-column diffractions from neighboring seamounts, it is very strange that they would not appear on the HMs. Could they be interface waves?

Figures 4 and 5 show spectrograms for the vertical geophone and co-located HM on the West OBS. The geophone appears to be much more sensitive than the HM to storm-related noise in the 0.2-1Hz and 100 - 350Hz bands and to noise from surface shipping.

## IMPACT/APPLICATIONS

Leakage of energy into DSFAs will have at least three consequences. First, if energy leaks out of the waveguide in a systematic fashion, it will increase transmission loss for known modes in the waveguide. These will be scattering losses as opposed to intrinsic attenuation. If the leaked energy rumbles through the seafloor and re-emerges down range (as multipath arrivals), perhaps only to near-seafloor receivers, there will be less overall transmission loss (more signal). In this case interpretations may require new types of modes. Second, leakage into DSFAa will result in long-range detections and observations on non-traditional sensors such as deep boreholes in the seafloor in water depths well-below the critical depth. Third, the physics of short and long-range sound propagation that we are observing in the controlled-source transmissions also applies to local and distant shipping noise. For example, the DSFAs observed on NPAL04 provided a mechanism for taking long-range energy from 4250m depth into the deep shadow zone at 5000m depth. So the presence of DSFAs on various sensors requires a re-evaluation of the signal and noise energy budgets.

## TRANSITIONS

Transitions to 32ASW project "Behavior of very low frequency near bottom ambient noise in deep water".

## RELATED PROJECTS

LOAPEX - ONR Award Number N00014-1403-1-0181

SPICEX - ONR Award Number N00014-03-1-0182

PhilSea09 and PhilSea10 - ONR Award Number N00014-08-1-0840

OBSAPS - ONR Award Number N00014-10-10994 and N00014-10-1-0990.

OBSANP - ONR Award Number N00014-10-10987 and N00014-12-M-0394

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Stephen, R. A., Bolmer, S. T., Udovydchenkov, I. A., et al. (in prep-a), Analysis of deep seafloor arrivals observed on NPAL04, (WHOI Technical Memorandum).

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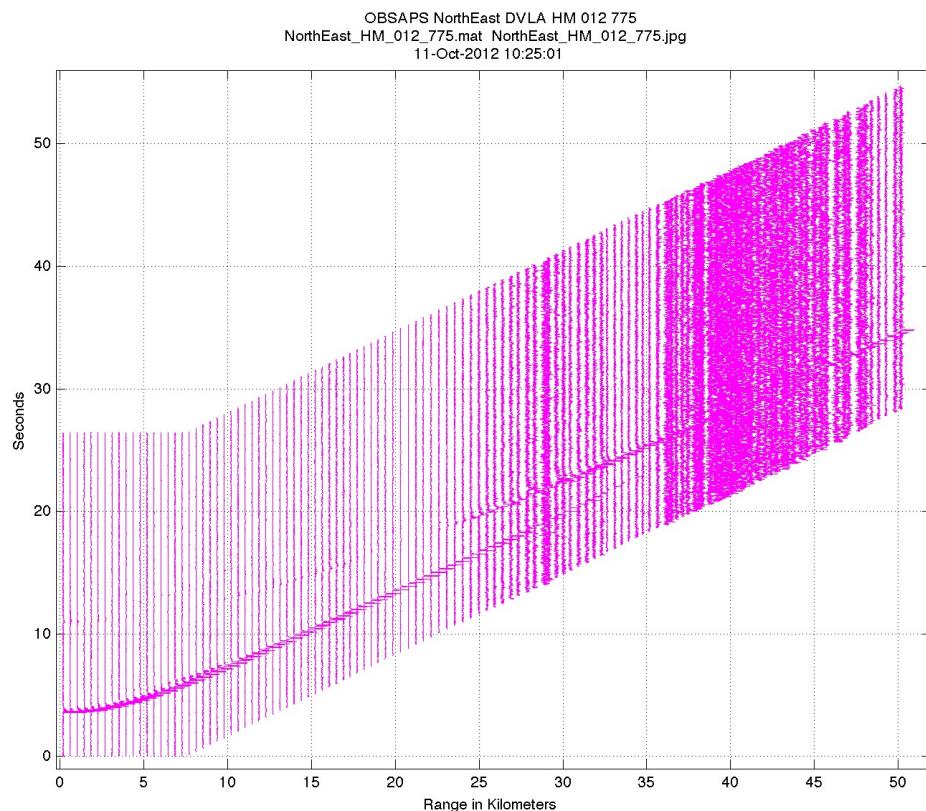
Stephen, R. A., Kemp, J., McPeak, S. P., et al. (2011), Ocean Bottom Seismometer Augmentation of the Philippine Sea Experiment (OBSAPS) Cruise Report, WHOI Technical Report 2011-04, (Woods Hole Oceanographic Institution, Woods Hole, MA).

## PUBLICATIONS

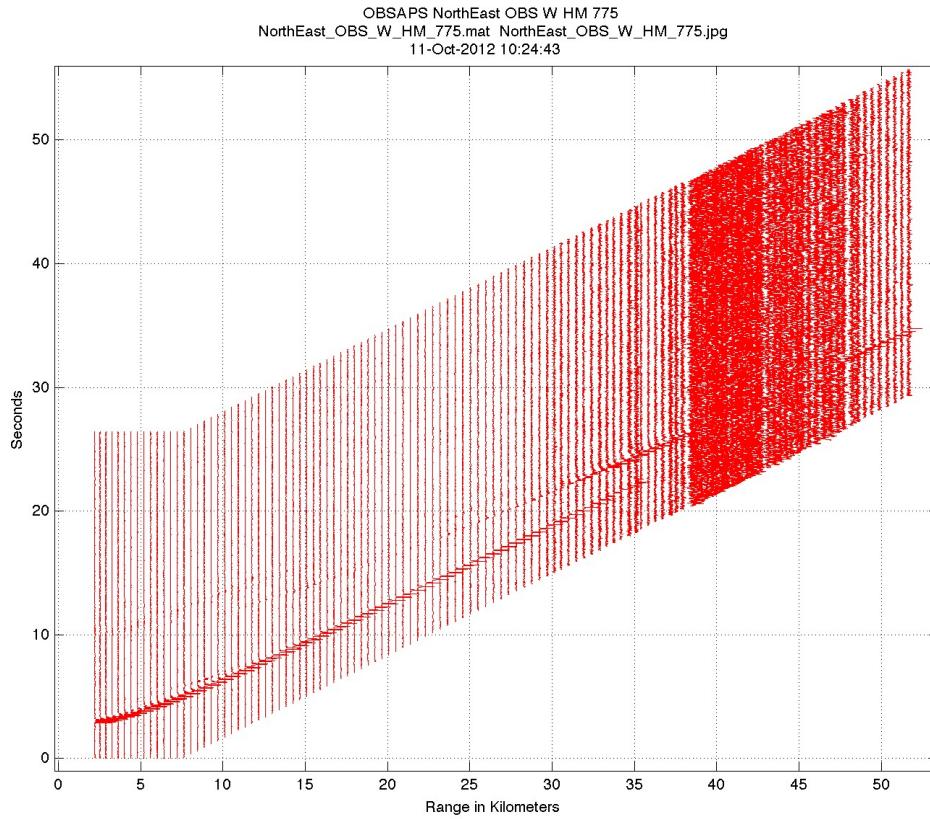
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## HONORS/AWARDS/PRIZES

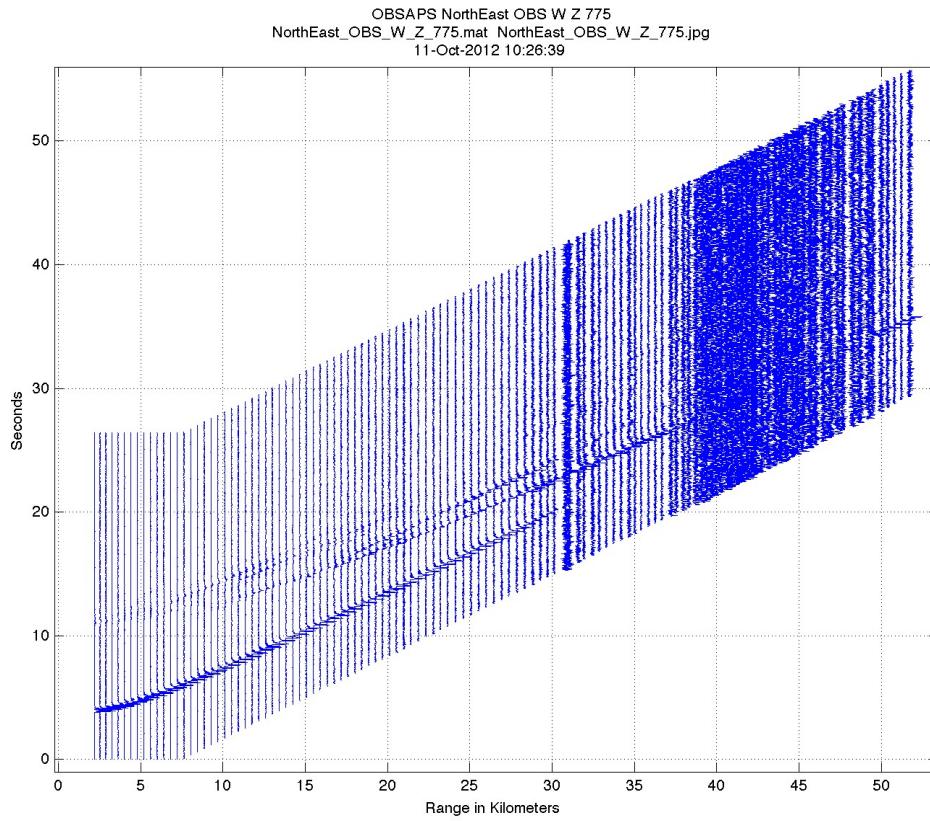
Ralph Stephen, WHOI, Edward W. and Betty J. Scripps Chair for Excellence in Oceanography, WHOI.



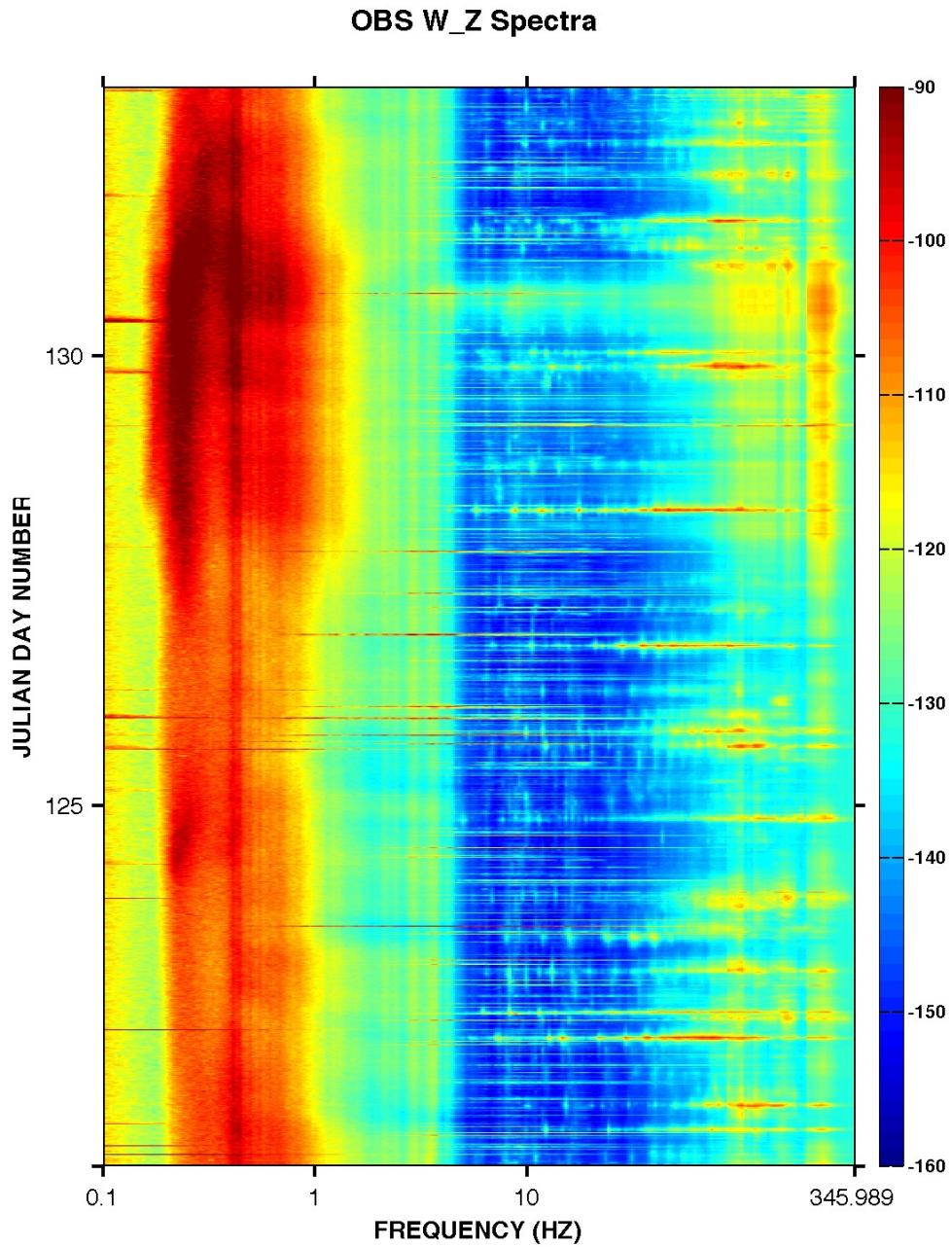
**Figure 1: Time series of time compressed traces (incoherently stacked over three transmissions) for the Northeast line and M77.5 transmission to the Hydrophone Module (HM) on the O-DVLA 12m off the bottom. All traces are normalized to the maximum amplitude of the trace. SNR deteriorates between half and one-and-a-half convergence zones, roughly 36 to 48 kilometers range. There is a strong direct path out to 30km range followed by a water column multiple (BRSR) from 25 to 50km. These are the textbook arrivals and there do not appear to be any other significant arrivals.**



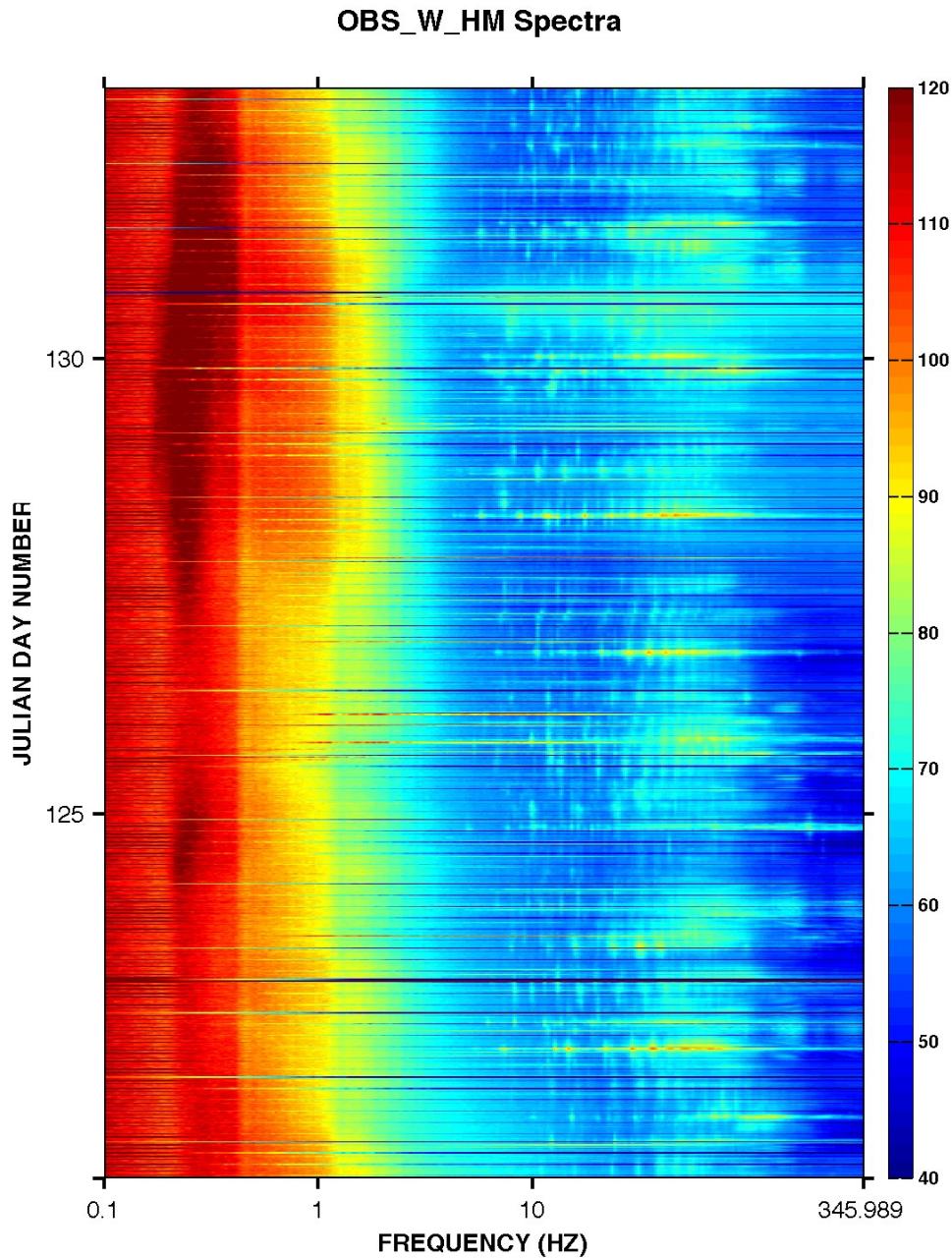
**Figure 2:** Stacks of the same transmissions as in Figure 1, but to the Hydrophone Module attached to the West OBS, about 1m above the seafloor. The West OBS is about 2km further in range from the source transmissions. The SNR and arrival structure are very similar to the structure for the HM suspended on the DVLA at 12m off the bottom (Figure 1).



**Figure 3:** Stacks of the same transmissions as in Figures 1 and 2, but for the vertical geophone on the West OBS, essentially co-located with the HM in Figure 2. In addition to the direct and BDSR arrivals there are two new unexplained arrivals. One is about seven seconds later than the direct path between roughly 10 and 15km. The other appears tangent to BDSR at 17km but is 4seconds later than BDSR at 30km. These are similar characteristics to the Deep Seafloor Arrivals (DSFAs) that were observed on NPAL04 (Stephen et al., 2009; Stephen et al., 2008; Stephen et al., in prep-a; b), but are occurring at much shorter range. They could be diffractions from off-axis seamounts, but it is strange that they are so much weaker, relative to the direct path, on the co-located hydrophone. Examples of the receptions from 7 to 13km range are shown on other elements of the DVLA and on the South OBS in Figure 30 of the cruise report (Stephen et al., 2011).



*Figure 4: Spectrogram (in dB re:  $1(m/s)^2/Hz$ ) for the vertical geophone on the West OBS. Surface wave generated noise, due to the passing typhoon around day 130 is apparent in the 0.2 to 1Hz and 100 to 350Hz bands. Horizontal red bands from 0.1 to 10Hz are earthquakes. Horizontal red bands from 10 to 100Hz are passing ships. Samples of line psds are shown in Figures 35 to 37 of the cruise report (Stephen et al., 2011).*



*Figure 5: Spectrogram (in dB re: 1microPascal<sup>2</sup>/Hz) for the hydrophone module on the West OBS, essentially co-located with the vertical geophone in Figure 4. Even though the HM is not calibrated well below 4Hz, surface wave generated noise, due to the passing typhoon around day 130 is still apparent in the 0.2 to 1Hz band. The HM appears to be less sensitive to the surface-wave generated noise in the 100 to 350Hz band and to surface shipping than the vertical geophone in Figure 4. Samples of line psds are shown in Figures 31 to 34 of the cruise report (Stephen et al., 2011).*